

# Deployment of COUPP-60 at SNOLAB

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## **ABSTRACT**

We propose to deploy the COUPP-60 dark matter detector at the SNOLAB underground laboratory. At SNOLAB, it will join the COUPP-4 detector, which has been running since 2010 and has demonstrated very low background levels due to intrinsically high levels of radio purity, insensitivity to gamma rays and acoustic rejection of alpha particle induced events. With 60 kg of  $\text{CF}_3\text{I}$  target liquid, COUPP-60 is anticipated to obtain world-leading sensitivity to Weakly Interacting Massive Particles (WIMPs) interacting through either spin-dependent or spin-independent couplings. We expect to complete a six-month initial physics run in 2012, accumulating an exposure of more than 5000 kg-days, an order of magnitude larger than our current SNOLAB data sample from COUPP-4.

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## 1 Introduction

COUPP is an experimental campaign with the goal of detecting dark matter in the form of Weakly Interacting Massive Particles (WIMPs). The basic COUPP detector is a continuously sensitive bubble chamber, operated under mildly superheated conditions. Recoils of dark matter particles off the target nuclei in the chamber would produce single, isolated bubbles, which are detectable both optically and acoustically. The target fluid used is the fluorocarbon  $\text{CF}_3\text{I}$ , which combines the advantages of a heavy isotope  $^{127}\text{I}$  for high sensitivity to spin-independent WIMP-nucleon interactions and an isotope with a strong spin coupling  $^{19}\text{F}$  to search for spin-dependent interactions. Under normal operating conditions, the detector has an energy threshold for nuclear recoils of approximately 10 keV but is insensitive to electron recoils, which typically constitute the background in dark matter searches. Nuclear recoils can be discriminated from alpha decays in the target liquid by inspection of the acoustic signal produced by the bubbles, which show excess power at high frequencies for alpha events. Nuclear recoils produced by WIMPs can be distinguished from those produced by neutrons on a statistical basis by the absence of multiple site interactions that are characteristic of neutron scattering.

The COUPP bubble chambers (COUPP-2, COUPP-4 and now COUPP-60) have been developed and tested at shallow underground sites near the collaborating institutions, including a basement at the University of Chicago and the NuMI near detector tunnel at Fermilab. These sites were useful for the early development of the technology since they are near our home institutions and, until very recently, the backgrounds from cosmic rays were subdominant to backgrounds from radioactive impurities in the detectors. However, with recent improvements in radiopurity and discrimination power, the cosmic ray induced backgrounds now limit both the possible dark matter sensitivity and our ability to study any residual internal backgrounds. Therefore, a move to a much deeper underground site is mandatory in order to make further progress.

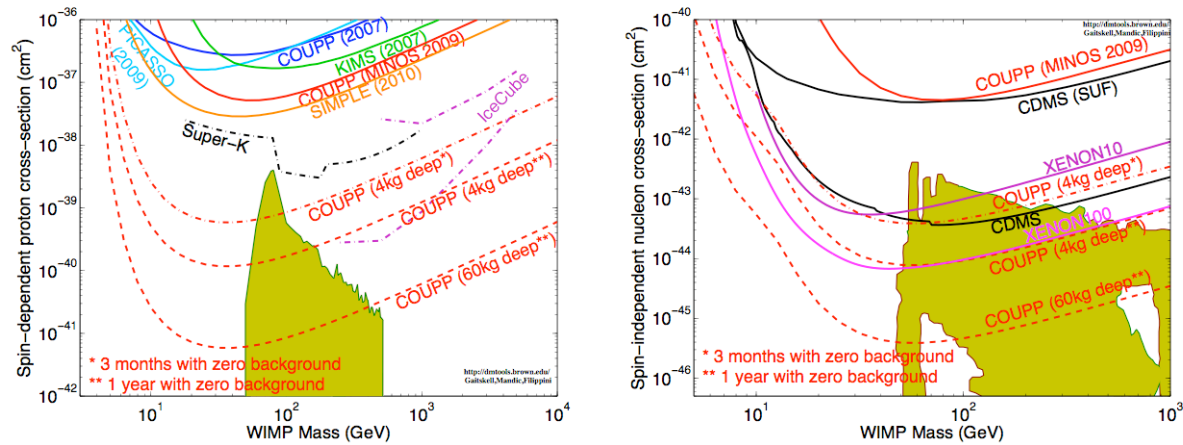
We propose to move the COUPP-60 detector to the SNOLAB underground laboratory, where, at 2-km underground, the background from cosmic-ray produced neutrons can be reduced by more than 4 orders of magnitude with respect to the levels we measure at Fermilab. Depending on the internal backgrounds encountered and the efficiency of acoustic alpha/nuclear recoil discrimination, the experiment has the potential to lead the field in both spin-dependent and spin-independent sensitivity, with quite dramatic discovery potential for WIMPs (Figure 1).

The major elements of the work plan envisioned by the COUPP collaboration in FY11-FY12 are listed below.

*COUPP-60 relocation, commissioning and initial physics run.* Most of the funding requested from DOE in FY12 will be used for the relocation and recommissioning of the COUPP-60 detector. The COUPP FY11 Field Work Proposal [1] described the steps needed for the preparation of the move of COUPP-60 from Fermilab to SNOLAB. These steps included improvements to the illumination and video systems, preparation of a safety plan, R&D on chemical stability issues and the packaging of the detector components for shipment. The current FY12 proposal picks up where the previous one left off and requests the remainder of the funding needed to assemble, commission and operate the detector at SNOLAB. The work planned is detailed in Section 5. The installation at SNOLAB will begin when testing at Fermilab

and the site preparations are complete. The installation and commissioning are expected to take about 6 months. The installation will be followed by a six-month initial physics run, accumulating approximately 5000 kg-days of exposure. This will be sufficient to fully characterize the background performance and produce an initial physics result.

*Continued operation of the COUPP-4 chamber at SNOLAB.* Operation of the COUPP-4 is expected to continue to produce valuable technical and scientific results. In the near term, we expect that it will have the world's best sensitivity to dark matter interacting by spin-dependent couplings (Figure 1 and Ref. [2]). The detector has served an essential role as a pathfinder for COUPP-60 by giving an early experience of SNOLAB operations and information on backgrounds. An important example of this is the discovery in 2011 of a neutron background due to radioactive impurities in the piezoelectric material used to fabricate the acoustic sensors attached to the COUPP-4 inner vessel. This resulted in a R&D effort, led by Virginia Tech, to develop a new low-radioactivity piezoelectric material that will be used for COUPP-60. When COUPP-60 is fully operational, we expect that COUPP-4 will continue to be important for tests of operating modes and equipment improvements that would be impractical to explore for the first time in the larger chamber. Several equipment upgrades are planned, including low-radioactivity acoustic sensors and higher-precision hydraulic controls. The collaboration is studying the possibility of using COUPP-4 with liquids other than  $\text{CF}_3\text{I}$  and at higher than usual temperatures and pressures to search for low-mass WIMPs.



*Figure 1: Sensitivity of zero-background experiments at SNOLAB for spin-dependent scattering (left) and spin-independent scattering (right). Physics sensitivity projections are shown for the already-installed COUPP-4 detector and for COUPP-60. Also shown (marked 'MINOS 2009') are the best existing COUPP limits from the NuMI tunnel, recently published in Phys. Rev. Lett. [2].*

*Calibration of superheated liquid response to nuclear recoils and backgrounds with small test chambers.* Our extended physics reach will require a more precise understanding of our nuclear recoil detection threshold and near-threshold efficiency. Improved threshold measurements will be made with a new Fermilab test chamber under construction in FY11 and with another small chamber built by collaborators at Argonne National Laboratory. The initial calibration data will

consist of exposures to radioisotope neutron and gamma sources. The response of the detector will be measured as a function of pressure and temperature, with the resulting count rates compared to Monte-Carlo predictions in order to derive constraints on models of the threshold behavior and background discrimination power. A second round of experiments are under study that would use accelerator-produced beams of neutrons, gammas and pions. The use of these other radiation sources has the potential to give much more detailed information in the threshold, particularly at low energies where radioisotope sources are limited.

## 2 The Bubble Chamber Technique

The COUPP detectors are continuously-live, mildly superheated bubble chambers operating below the threshold for sensitivity to minimum ionizing particles. This simple technology offers an attractive route to low background, low-cost dark matter detectors with multi-ton target masses. Bubble nucleation in a superheated fluid requires a minimum energy deposition, which can be supplied by a particle interaction. As illustrated in Figure 2, the additional requirement of achieving a critical energy density in order to nucleate bubbles allows for operating modes which discriminate between different particle interactions on the basis of their specific stopping power ( $dE/dX$ ). Since nuclear recoils deposit their energy in very short length scales (tens of nanometers) as compared to electrons (micrometers) of the same energy, an appropriate choice of operating parameters will result in a bubble chamber that is sensitive to nuclear recoils but blind to minimum ionizing particles and  $\gamma$  and  $\beta$  interactions. The collaboration has demonstrated that the intrinsic rejection against  $\gamma$  interactions is larger than  $10^{10}$  at a nuclear recoil threshold of 10 keV. This is the same background discrimination mechanism that has been used successfully in superheated droplet detectors such as PICASSO [3] and SIMPLE [4].

Nuclear recoils due to the  $\alpha$  decay of radioactive atoms in the target fluid present a potential source of background. For example,  $^{222}\text{Rn}$  (radon) decays by emission of a 5.5 MeV alpha particle into  $^{218}\text{Po}$ , which in turn recoils with 101 keV of kinetic energy, well above the 10 keV trigger threshold. There are two potential sources of such radioactive atoms, those that enter as residual contamination in the chamber fluids and those that are injected as decay daughters from the inner surfaces of the target fluid vessel. We have two independent approaches to this problem: reduction of the contamination of fluids and surfaces, and detection techniques to identify and reject  $\alpha$  decay events.

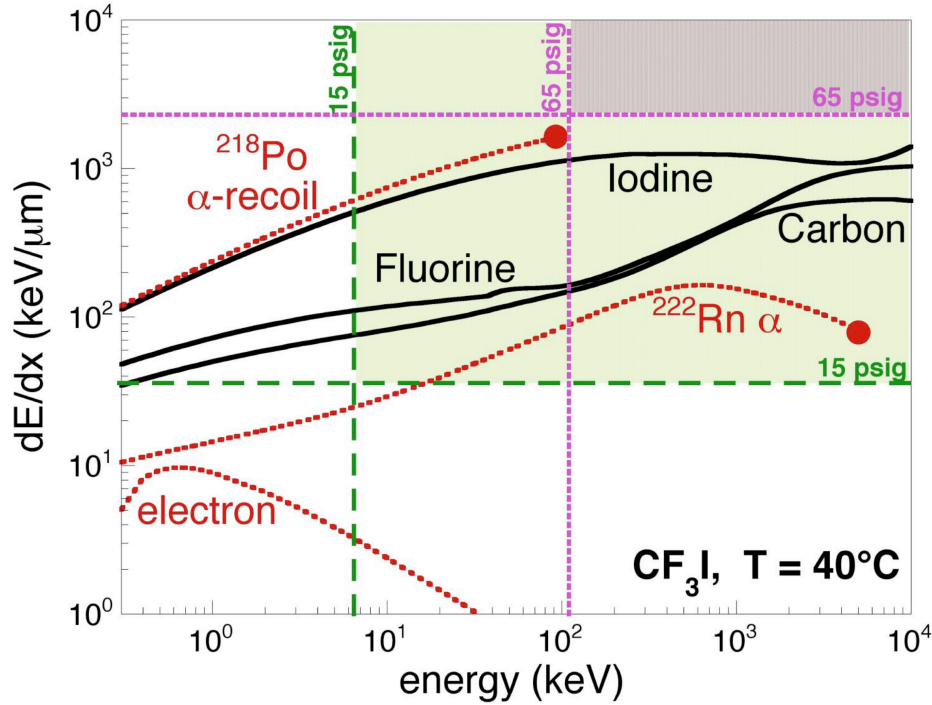
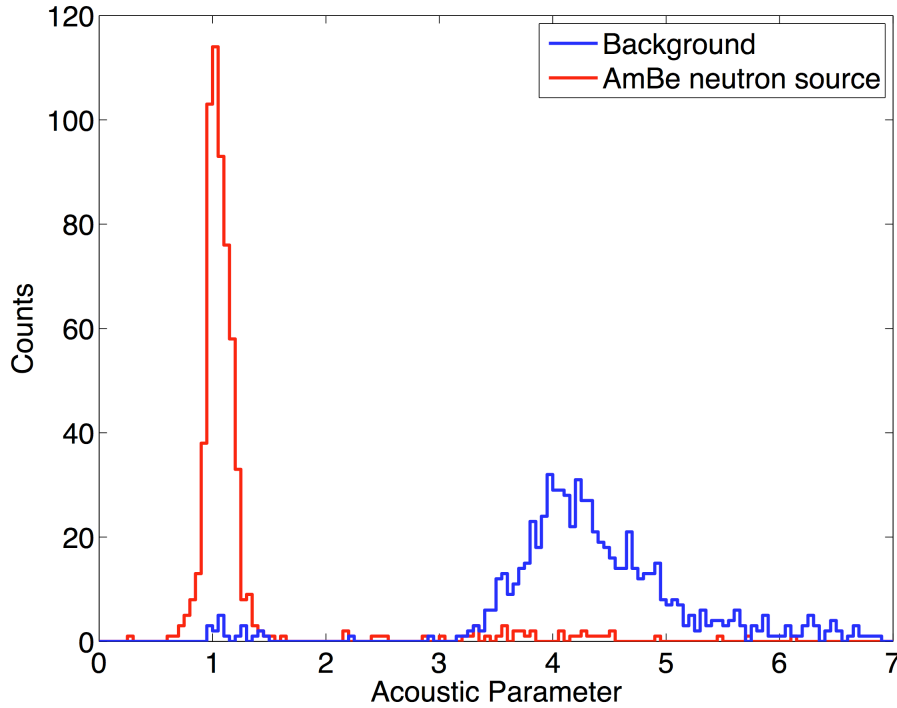


Figure 2: Chart illustrating the dependence of bubble nucleation on both the total deposited energy and  $dE/dx$ . The purple (green) shaded regions in the upper right quadrant of the plot indicate the region of efficient bubble nucleation for 65 psig (15 psig). The bubble nucleation physics creates thresholds in both  $dE/dx$  and in total energy deposited. The curves on the figure show the relationship between energy and  $dE/dx$  for a variety of particles. The red curves describe backgrounds from electrons, from the alpha particles produced in  $^{222}\text{Rn}$  decays and from the recoiling  $^{218}\text{Po}$  daughter nucleus following  $^{222}\text{Rn}$  decay. The black curves describe iodine, fluorine and carbon nuclear recoils. Both the insensitivity to electron and gamma backgrounds and the sensitivity to alpha decay backgrounds are apparent.

Radon decays in the target fluid were the dominant source of events in the first published COUPP results [5]. We also saw large numbers of  $\alpha$ 's coming from the walls of the natural quartz jar that was used at the time. In subsequent chambers we used synthetic quartz jars, reducing the wall rate to levels 2-3 orders of magnitude below the natural quartz rate. We achieved  $\alpha$  decay rates in the working fluid of  $\sim 1/\text{kg/day}$  in the COUPP-4 and COUPP-60 runs in the NuMI tunnel. We hope to reach state of the art levels of  $\alpha$  activity in chamber liquids, as defined by the solar neutrino experiments Kamland, Borexino, and SNO. These experiments have achieved  $\alpha$  activities in water and scintillator at the  $10^{-2} - 10^{-4} / \text{kg/day}$  levels depending on the technique, liquid, and isotope.



*Figure 3: Acoustic Parameter (AP) for background events (blue) and events from an AmBe neutron source (red). Data is from the SNOLAB run of the COUPP-4 device after a 3.3 kg fiducial cut (5 mm in from quartz walls). The alpha peak in the background is well separated from the nuclear recoil peak in the neutron data, and we measure an  $\alpha$  rejection of  $>98\%$ . The high AP tail in the neutron data has been seen in previous calibrations, although in this case most of the tail is due to alphas present in the neutron calibration. The background events in the nuclear recoil peak are at least partially due to a neutron background.*

In the last two years, a new acoustic technique has been developed for rejection of alpha background events. In 2008, the PICASSO collaboration discovered that events initiated by alpha decays have louder acoustic emissions than events initiated by neutron scattering [6]. This is speculated to be due to the difference between the single proto-bubble formed by the short range ( $\sim 100\text{nm}$ ) nuclear recoil and the multiple proto-bubbles from the longer range track ( $\sim 35$  microns) of the  $\alpha$  particle. Regardless of cause, the observed fact is that events initiated by alpha decays are louder and have larger contributions at high frequencies than do those initiated by neutrons.

We have recently confirmed and improved on the PICASSO result, demonstrating event-by-event discrimination of bubbles produced by alpha radioactivity from those produced by neutrons. Figure 3 shows the distribution of an acoustic parameter (AP) representing the loudness of an event for different types of events recorded by the COUPP-4 device in SNOLAB. We have now demonstrated  $>98\%$  alpha rejection. The background nuclear recoil-like events appear to be from sources besides  $\alpha$  decays. In view of the excellent separation between recoil and alpha events, we expect the discrimination bound to continue to improve once these backgrounds are eliminated.



The target fluid of choice for the COUPP program is trifluoroiodomethane ( $\text{CF}_3\text{I}$ ), which has a density of  $2 \text{ g/cm}^3$ . Because of its modest boiling point, it is possible to operate a  $\text{CF}_3\text{I}$  bubble chamber very near atmospheric pressure and room temperature.  $\text{CF}_3\text{I}$  provides excellent sensitivity to spin-independent couplings because of the large  $A^2$  enhancement for scattering on iodine and excellent sensitivity to spin-dependent couplings by virtue of the fluorine, which has  $\sim 100\%$  isotopic abundance of spin  $\frac{1}{2}$   $^{19}\text{F}$  and has a favorable nuclear form factor. We note that other liquids with interesting target characteristics, such as  $\text{C}_4\text{F}_{10}$ , could be used as a drop-in replacement for  $\text{CF}_3\text{I}$ . This potential for changing the target composition allows a powerful check against backgrounds and ultimately the possibility of measuring the cross section scaling of WIMP scattering with respect to atomic mass and spin.

### 3 History

Our first clear technical demonstration of the stable bubble chamber technology was accomplished with a 12ml “test-tube” chamber filled with  $\text{CF}_3\text{Br}$ . With this device, operated during 2002-2003 at the University of Chicago, we were able to demonstrate sensitivity to neutron-induced nuclear recoils and threshold behavior that were both consistent with theoretical expectations and promising for dark matter searches. We were also able to demonstrate excellent immunity to electron recoils. This laid the platform for the next stage – a 2kg chamber.

#### 3.1 COUPP-2 (T945)

The 2kg COUPP-2 chamber was designed, built, and commissioned at the University of Chicago in 2004. The COUPP-2 bubble chamber introduced the use of a standard, ASME code-rated stainless steel vessel for pressure containment. The safety of the operators and environment was the single most important consideration in implementing this design, which guarantees gas and fluid containment in event of a rupture of the quartz inner vessel. The design also greatly reduced the probability of failure by minimizing the stress on the quartz and permitted easy scalability, since even very large steel pressure vessels are relatively simple to design and procure.

Because the superheated liquid is insensitive to gamma rays from radioactive impurities in the steel and other construction materials, this chamber was constructed without any special screening process or clean assembly. The use of commercially available components, industry standard materials and construction techniques allowed us to bring the detector on-line very quickly and at low cost. The 2kg chamber was designed, built and commissioned in 14 months with an M&S cost of approximately \$40k.

Following a successful evaluation test at the University of Chicago, the COUPP-2 bubble chamber came to Fermilab in March of 2005 and was operated 300 feet underground in the NuMI near detector tunnel. While not sufficiently deep for most competitive dark matter searches, the NuMI site proved to be a very convenient location for development of the bubble chamber technology. In the first successful NuMI run in 2006, we were able to demonstrate reliable, stable operations. We developed temperature and pressure controls and optical triggering using the video camera data.

In the 2006 NuMI run, we observed a significant count rate from the decay of radon and radon daughters in the active fluid. Radon was injected into the system during the chamber filling



process, and we also observed a continuous injection of radon into the vessel throughout the run that was ultimately attributed to a Viton rubber O-ring used in the quartz-to-metal seal between the bellows and the quartz inner vessel. We observed a significant count rate of  $\sim 1$  event/cm<sup>2</sup>/day of bubbles nucleating on the walls of the quartz vessel. While not a background per se, the rate of these events was of concern because it would limit our ability to scale the detector up to a larger volume. The wall nucleation rate was ultimately understood to arise from the intrinsic uranium and thorium contamination of natural quartz. Decays of these nuclei and their daughters result in the emission of alpha particles into the fluid providing a source of bubble nucleation. Despite the wall event and radon decay rate, we were still able to establish significant new limits on spin-dependent WIMP nucleon scattering [5].

### 3.2 COUPP-4 (T945-A2)

To address the technical and background issues seen in the 2kg chamber, we initiated an upgrade in 2007, labeling it COUPP-4. The goals were:

- a) To construct an improved muon veto/neutron shielding system.
- b) To test improved DAQ and controls hardware and software.
- c) To test the use of a synthetic silica vessel to address the “wall event” issue.
- d) To test improved materials choices for fluid handling and seals.
- e) To test the use of acoustic transducers for the rejection of alpha-decay events.

The upgrades to the 2kg bubble chamber were completed over a two-year period and the apparatus was re-commissioned in the fall of 2009. The new apparatus used a liquid scintillator tank to provide neutron shielding and tagging of cosmic ray muons. The new inner vessel was fabricated from a 6” diameter sample of synthetic silica replacing the original 4” diameter vessel and allowing us to increase the target mass to 4kg. The data acquisition was based on a National Instruments PXI system with an embedded processor. Controls improvements included a microprocessor-based pressure control system and a closed loop temperature regulation system. Improvements in material selection included replacement of the Viton rubber seals with Teflon coated nickel-inconel seals and replacement of polyethylene tubing with Teflon in our CF<sub>3</sub>I handling equipment.

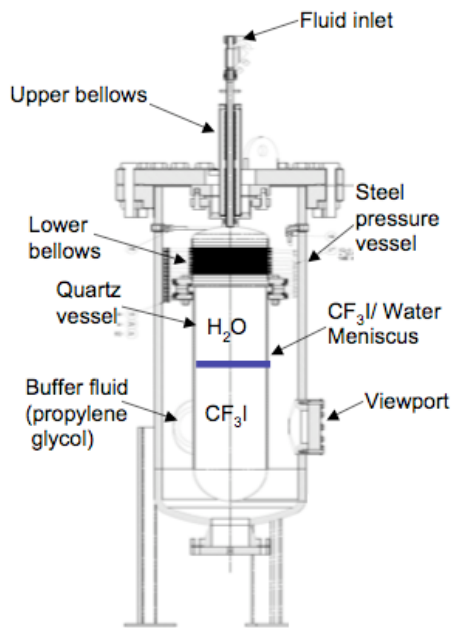
The 2009 run of the COUPP-4 chamber was successful in all of its goals. The DAQ and controls system operated without operator intervention for months at a time. Temperature and pressure regulation performance exceeded our requirements. From the beginning, it was clear that the overall count rates were significantly improved. The “wall event” bubble nucleation was entirely eliminated by the use of high radiopurity synthetic silica for the vessel, opening the way to contemplation of ton-scale chambers. The initial radon rate observed in the chamber was consistent with less than 100 radon atoms injected at the fill, significantly better than our past efforts. After decay of the initial radon injection, the observed rate of alpha decay events in the chamber was less than 1 event/kg/day. The most significant result was a clear confirmation of the difference in acoustic signature between alpha decay events and nuclear recoils. Using the acoustic alpha discrimination, we were able to set improved limits on spin-dependent WIMP couplings [2]. Ironically, the lack of radon contamination in the chamber limited our ability to evaluate the power of the alpha recoil discrimination.

The NuMI run of the 4kg chamber was cut short by a failure of the hydraulic controls system that led to an overextension of the inner vessel bellows. The replacement of the damaged bellows required only a modest effort, but because of the exceptional performance we had already seen and because the physics reach of the detector in the NuMI site was already limited by cosmic ray induced events, we decided to re-deploy the 4kg chamber at a deep site.

### 3.3 COUPP-60 (E961)

Based on the successful early runs of the COUPP-2 detector, a 60kg device was proposed and approved at Fermilab in 2006. The detector was designed and built in the period 2007-2010 and commissioned in the NuMI tunnel. In 2009, proposals to Fermilab and SNOLAB were approved to move this detector to the deep underground SNOLAB site after initial testing at Fermilab.

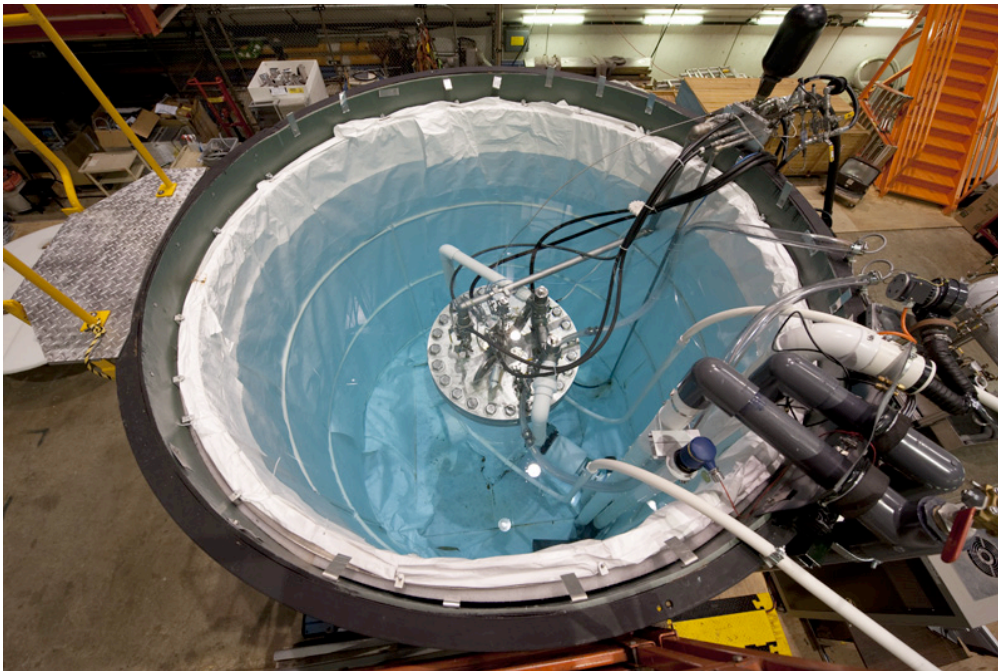
The COUPP-60 detector design is based on a scale up of the COUPP-2/4 design. We show a drawing of the chamber in Figure 4 and photos in Figure 5 and Figure 6. The superheated liquid is contained in a quartz vessel, with a volume of pure water floating on top. The water isolates the superheated liquid from contact with a set of metal pressure-transmitting bellows. The bellows equalize the pressure inside the quartz with the pressure of the surrounding buffer fluid, thus maintaining low stress in the quartz. The buffer fluid and quartz inner vessel are inside a conventional stainless steel pressure vessel. Pressure control of the superheated liquid is provided by a piston and pump module connected to the buffer fluid. This design allows the pressure to be controlled in a completely hermetic, high purity environment.



*Figure 4: Drawing of the COUPP-60 bubble chamber (left) and photo of the steel pressure vessel (right). The active superheated fluid is contained inside a high-purity synthetic quartz vessel and covered on top by water, which fills the inside of a bellows. The bellows maintains pressure equilibrium between the inner vessel fluids and the hydraulic working fluid (propylene glycol) that fills the exterior steel pressure vessel.*



*Figure 5: Assembly of the COUPP-60 inner vessel. The detector was assembled in a Class 100 clean room to avoid contamination by alpha-emitting isotopes in dust. The parts for the assembly were fabricated and cleaned to semiconductor industry standards.*

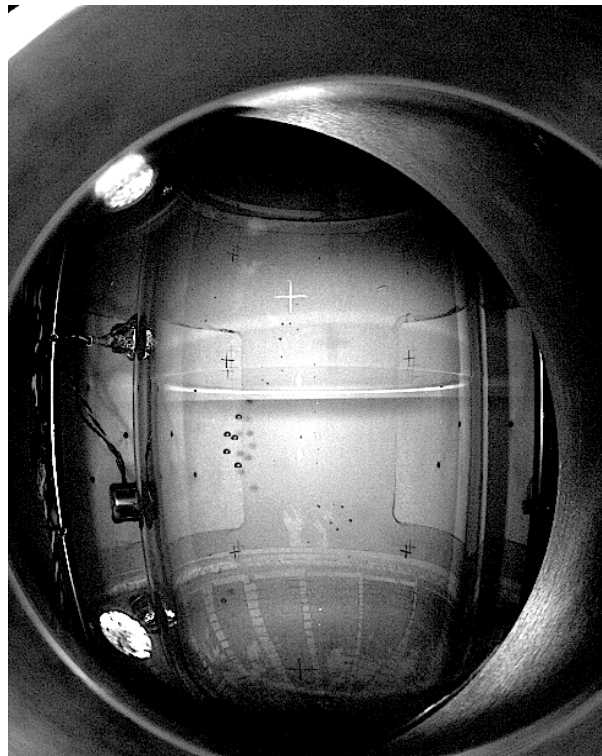


*Figure 6: The complete detector assembly nested inside the water shielding tank used at D0 and NuMI. The water tank is lined with white Tyvek sheets to improve collection of Cerenkov light by the muon veto phototubes, which are installed on a floating lid (not shown).*



The detector is installed inside an insulated water tank (Figure 6) which provides a shield against environmental neutrons. The temperature of the water, controlled with a heater, is used as the thermal regulator for the detector. For operation at our shallow commissioning site (the NuMI tunnel at Fermilab), phototubes float on a foam raft on the top of the water, turning the tank into a water Cerenkov detector for cosmic ray muon detection.

The sensitive volume inside the quartz inner vessel is viewed by a stereoscopic pair of video cameras. A sample image from one camera is shown in Figure 7. The detector is triggered by comparing each video frame to a reference image. If there are a significant number of pixels that have changed their intensity, then a fast compression of the detector is induced, forcing any bubbles that may have formed to reenter the liquid phase. A set of video frames and chamber status information corresponding to the event is stored. The analysis of these data determines whether a single bubble occurred (WIMPs will never produce multiple scatters) and whether the bubble occurred in the bulk volume, rather than on one of the surfaces of the vessel or at the boundary between the  $\text{CF}_3\text{I}$  and the water.



*Figure 7: Sample image from COUPP-60 NuMI run showing an event with 6 bubbles from multiple neutron scattering. The interface between the  $\text{CF}_3\text{I}$  volume (40 kg for this test) and the water floating on the top of the  $\text{CF}_3\text{I}$  is clearly visible. The bubbles are photographed with high contrast. As discussed in the text, good lighting conditions were obtained over the central region of the detector, with poor lighting towards the bottom and top.*

## 4 Progress in FY11

In the three months that have passed since the previous proposal [1] was written, the collaboration has continued to operate the COUPP-4 detector at SNOLAB, using primarily NSF funding that was provided through the University of Chicago. Most of the operation is remote-controlled, and help with routine maintenance issues has been provided by local collaborators, with only a few visits by University of Chicago personnel required in the six months since the detector was installed. The chamber continues to run well and exhibit very low backgrounds. The collaboration plans to end the current run in June, 2011, when a data set containing approximately 400 kg-days of exposure will have been accumulated. This exposure was chosen on the basis that, should the background rates be sufficiently low, a competitive spin-independent result could be obtained. Several options are under consideration for running of COUPP-4 beyond June, including a low-threshold WIMP search at higher operating temperatures and tests with target liquids other than  $\text{CF}_3\text{I}$ .

Benchtop tests of  $\text{CF}_3\text{I}$  purity, chemical compatibility and sensitivity to light exposure have continued, motivated by the discovery in 2010 that the  $\text{CF}_3\text{I}$  in COUPP-60 was degrading during chamber operation, causing a reduction in transparency and interfering with photography of the bubbles [1]; this degradation had not been observed in a significant fashion in previous chambers. The cause of the degradation is now known to be the exposure of  $\text{CF}_3\text{I}$  to the intense red LED light that is used for video photography. While it is well known that UV light will break the C-I bond, it appears that the red light used for illumination also reacts with the  $\text{CF}_3\text{I}$ , releasing free iodine that begins to noticeably discolor the normally clear  $\text{CF}_3\text{I}$  in concentrations of as little as a few parts per million. The effect is proportional to the light intensity and decreases towards longer wavelengths, with no noticeable effect from arbitrarily large light exposures at 950 nm (the normal exposure being at 630 nm). We have investigated the effects of contact between  $\text{CF}_3\text{I}$  and chamber construction materials, including stainless steel, water, Teflon and gold, both in darkness and in the presence of light of various wavelengths. The conclusion of these studies is that exposure to the red light of our chamber illumination system is alone sufficient to cause the observed degradation, with none of the other variables clearly accounting for the absence of decomposition in previous chambers. Direct contact with some construction materials, including stainless steel, appears to inhibit the decomposition of  $\text{CF}_3\text{I}$  and may account for the discrepancy between COUPP-60 and previous runs, as may the presence of impurities beyond our current detection capabilities.

The plan we have chosen for solving the degradation problem in COUPP-60 is to reduce the level of light exposure by using a less powerful illumination source that is turned on and off in synchronization with the electronic shutter of the video cameras. New video cameras will be procured that require only 10% of the current illumination level, due to their lower read-out noise. These improvements will allow photography with 1-2 orders of magnitude less light than the present setup. In addition, we will add small amounts of the compound  $\text{Na}_2\text{SO}_3$  to the water filling the top part of the inner vessel. This compound removes water-insoluble molecular iodine from  $\text{CF}_3\text{I}$  by converting it to iodine ions, which are both transparent and preferentially soluble in water. The addition of  $\text{Na}_2\text{SO}_3$  has been studied in a small chamber built by our collaborators at Argonne National Laboratory, where it has inhibited the discoloration of  $\text{CF}_3\text{I}$  with no other

evident effect on bubble chamber operation. A full scale test in COUPP-60 is planned to occur in June.

Recent progress has been made at Fermilab in improving the purity of  $\text{CF}_3\text{I}$ . A number of impurities have been detected in our supply of  $\text{CF}_3\text{I}$ , including  $\text{CO}_2$ ,  $\text{CHF}_3$ ,  $\text{C}_3\text{F}_6$ ,  $\text{C}_2\text{HF}_5$  and  $\text{C}_3\text{HF}_5$ . These impurities are believed to be introduced by the manufacturing process, but the possibility that some are due to chemical reactions occurring during storage or chamber operation can not be precluded. In samples taken from the 2010 commissioning run of COUPP-60, the fraction of  $\text{CO}_2$  reached as high as 3%, a level which may account for excess bubbling from the  $\text{CF}_3\text{I}$  surface seen during parts of that commissioning run. We have found that  $\text{CO}_2$  can be removed from  $\text{CF}_3\text{I}$  by passing it through a column of molecular sieve. The level of  $\text{CO}_2$  has been reduced by at least a factor of six to the level observed in the fluid used for the SNOLAB run of COUPP-4, with any remaining impurity in both samples hidden by the high backgrounds of the mass spectrometer gas analyzer currently available at Fermilab. The molecular sieve filter is also expected to be efficient for the other small-molecule contaminants mentioned above. Future analysis by gas chromatography mass spectroscopy (GCMS) will reveal the true levels remaining after purification. Purified  $\text{CF}_3\text{I}$  will soon be tested in COUPP-60 to see if it improves the stability of the detector to surface bubbling at the relatively high operating temperatures ( $\sim 40$  degrees C) required for a competitive low- threshold WIMP search.

## 5 Scope of This Proposal

The funding requested for FY12 will support activities listed below. These activities assume as a prerequisite the completion of the tasks described in our FY11 proposal [1], including the packaging of the detector for shipment to SNOLAB, the installation of special safety equipment at SNOLAB for handling the exhaust of  $\text{CF}_3\text{I}$  gas and the acquisition and testing of low noise video cameras with their associated data acquisition electronics.

- (1) Relocation of all COUPP-60 equipment from Fermilab to the SNOLAB underground area. The major pieces of the detector are: the inner vessel, the outer vessel, the hydraulic skid, the high purity fluid skid, the glycol handling skid and the data acquisition system. The handling of most of these shipments will be routine, but the inner vessel will require special care because of its fragility. Engineering studies will be completed with FY11 funds to insure that the inner vessel is packaged appropriately to survive shipping.
- (2) The acquisition of personal protective equipment, including respirators that can be used with  $\text{CF}_3\text{I}$  gas and gas release alarms. The details on the type of protective equipment and protocols for use will be decided after the planned FY11 engineering study of  $\text{CF}_3\text{I}$  release scenarios and venting requirements.
- (3) The preparation of the detector assembly site. This work, which is a joint Fermilab and SNOLAB responsibility, includes the assembly of a Class 100 clean room area for inner vessel work in FY12. Fermilab is also responsible for supplying tools, clean room consumables and task lighting.
- (4) Installation of the water handling and temperature control equipment on the water tank and testing of the water tank opening, closing, filling, temperature control and emptying.

- (5) The assembly of the detector inside the water tank. This task will be performed by a group of Fermilab scientists, engineers and technicians who will follow an assembly procedure very similar to the one used in the NuMI tunnel.
- (6) The installation of new, high-sensitivity cameras and a pulsed LED illumination system designed to minimize the exposure of  $\text{CF}_3\text{I}$  to light and improve video resolution. These cameras will be tested in FY11 and installed at SNOLAB in FY12. Spare cameras and readout electronics will be purchased to maintain a DAQ test stand at Fermilab.
- (7) The installation of a new Scotchlite reflector in the outer vessel. The reflector will be mounted on a metal foil with a shape optimized to improve illumination of the lower portion of the detector. This new reflector will be designed and tested in FY11 and installed in FY12.
- (8) A new set of acoustic sensors will be attached to the Inner Vessel. These sensors will be provided by collaborators from Virginia Tech and Indiana University. The sensors are expected to be fabricated from a new low-radioactivity piezoelectric material being developed at Virginia Tech.
- (9) The construction of fluid and electrical interconnections between the SNOLAB-provided utility lines, the bubble chamber fluid handling modules and the bubble chamber Inner and Outer Vessels. As much as possible, this work will be done by contracting local electricians and pipe fitters, with supervision by Fermilab physicists and engineers.
- (10) The installed detector system will be reviewed by Fermilab and SNOLAB staff to insure compliance with applicable Canadian regulations as well as the standard internal engineering practices of both laboratories. This review is anticipated to be similar to the “operational readiness clearance” review required for all Fermilab experiments.
- (11) The detector will be filled with fluids and commissioned. This process is expected to take several months and require the continuous on-site presence of a group of Fermilab scientists, together with more occasional trips by technicians and engineers. All detector subsystems will be tested during this period. The budget for commissioning includes the acquisition of 100 kg of  $\text{CF}_3\text{I}$  and purification of the  $\text{CF}_3\text{I}$  with a molecular sieve before it is loaded into the detector.
- (12) Initial Six-month physics run. This proposal includes operations funding for an initial six month physics run. This will be sufficient to accumulate an exposure of 5000 kg-days with an expected 75% live time fraction and ample run time devoted to in-situ neutron and gamma ray calibrations. The operations budget assumes the continuous presence on-site at SNOLAB of one Fermilab staff scientist or postdoc for this initial running period. To the maximum extent possible, without risking the integrity of the detector or data, an effort will be made to establish full remote control of the detector from Fermilab. This may in the longer term eliminate the need for on-site staff.
- (13) Computing. The budget for computing includes the purchase of a new 32-core server for data analysis, 6 TB of disk space for data and the maintenance of commercial software licenses used for data acquisition and analysis.
- (14) Outer vessel upgrades. The camera viewport on the outer vessel will be modified to reduce its radioactivity by replacing the current borosilicate glass window with high purity fused silica window. An additional viewport will be added to the vessel to improve the optics and camera mounting system. Additionally, a more extensive radiopurity and optics improvement to the outer vessel is under consideration. This option would involve



the procurement of a new pressure vessel made with special stainless steel selected for low levels of radioactive contamination.

- (15) Operation of COUPP-4. COUPP-4 will be operated continuously in FY11 and FY12, with pauses to incorporate updates to the DAQ and controls that are primarily the responsibility of the University of Chicago group. Updated low-radioactivity acoustic sensors will be tested on COUPP-4 before being attached to COUPP-60. Other plans for COUPP-4 include exposures to gamma and neutron sources and operation at high temperature and low pressure to search for low-mass WIMPs.
- (16) Calibrations with small chambers at Fermilab, Argonne and Notre Dame. Calibrations are expected employing radioisotope neutron and gamma sources and accelerator-produced neutron, pion and gamma beams. The budget for FY12 includes the updating of the Fermilab test chamber with the high precision hydraulic pressure control technology initially being supplied by the University of Chicago for COUPP-4. The budget also provides funding to support mounting a calibration chamber in a neutron beam line at the Nuclear Science Laboratory of the University of Notre Dame.

## 6 Budget

Our budget request is summarized in Table 1 below.

WBS	Task	FY11 k\$	FY12 k\$	Total k\$
1	Outer Vessel	24	58	82
2	Inner Vessel	12	30	43
3	High Purity Fluid Skid	6	42	48
4	Water Tank	20	21	41
5	Hydraulic Skid	8	23	32
6	Illumination	61	3	64
7	Utilities	2	0	2
8	Cameras	46	24	71
9	Data Acquisition	0	33	33
10	Computing	0	28	28
11	Control System	53	12	65
12	Safety Infrastructure	94	34	129
13	Site Infrastructure	2	33	35
14	OV Upgrades	9	95	104
15	Chemical Tests	57	0	57
16	Acoustic Sensors	39	3	42
17	Installation& commissioning Travel	0	106	106
18	Commissioning	0	102	102
19	Calibration	0	57	57
20	Operations	0	127	127
21	COUPP-4	52	52	104
22	Project Management	12	12	25
Totals		500	897	1397

*Table 1: Budget Summary Table for FY12. Overhead costs are included and are applied to labor and M&S based on current Fermilab Particle Physics Division estimates, with an escalation of 0.5% for 2012. All budget lines include 30% contingency.*

## 7 Schedule

The anticipated schedule of the experiment is summarized in Table 2 below. We anticipate installing COUPP-60 infrastructure items, such as the water tank and utility lines at SNOLAB in the Summer and Fall of 2011. During this period, as funding becomes available, the improvements to the COUPP-60 detector discussed in our FY11 Field Work Proposal [1] and in Section 5 will be initiated. When testing is complete, the detector will ship to SNOLAB, with

reassembly and commissioning continuing through March 2012. The first physics run will extend from April through September 2012.

The development of the improved hydraulic control system for COUPP-4 is planned during the summer of 2011, with installation at SNOLAB in the Fall. The construction of the acoustic test and calibration chamber will be completed at Fermilab in Summer 2011.

FY09	Complete fabrication and testing at D0
FY10	Commissioning of 60-kg detector at NuMI, 4-kg detector at SNOLAB
FY11	Installation of underground infrastructure for COUPP-60 COUPP-4 running and refurbishment at SNOLAB Acoustic sensor and chemistry R&D COUPP-60 testing at Fermilab
FY12	Install COUPP-60 underground at SNOLAB First COUPP-60 Physics Run at Snolab (5000 kg-days) COUPP-4 calibration runs at SNOLAB
FY13	COUPP-60 Running at SNOLAB

*Table 2: Coarse-grained COUPP schedule.*

## 8 References

- [1] “Preparations for the Deployment of COUPP-60 at SNOLAB”, FY2011 Field Work Proposal, FNAL 11-25, Proposal ID 11011233, Submitted March 17, 2011.
- [2] E. Behnke et al. (COUPP) Phys. Rev. Lett. 106, 021303 (2011)
- [3] M. Barnabe-Heider et al. (PICASSO) Phys.Lett.B624:186-194 (2005)  
and S. Archambault et al. (PICASSO) Phys. Lett. B682 1895-192 (2009)
- [4] T.A. Girard et al (SIMPLE) Phys.Lett.B621:233-238 (2005)  
and M. Felizardo et al (SIMPLE) Phys. Rev. Lett. 105, 211301 (2010)
- [5] E. Behnke et al. (COUPP), *Science* Vol. 319. no. 5865, pp. 933 – 936  
([www.sciencemag.org/cgi/content/full/319/5865/933/DC1](http://www.sciencemag.org/cgi/content/full/319/5865/933/DC1))
- [6] F. Aubin et al. (PICASSO), New J. Phys. 10, 103017 (2008)

## Appendix I

WBS Number	L2 Task	L3 Task	L4 Task	Minimum Duration [hours]	Expected Duration [hours]	Maximum Duration [hours]	Technician FTEs	Engineer FTEs	Physicist FTEs	Tech Hours	Engineer Hours	Phy Hours	M&S Cost [\$]	Expected M&S Cost [\$]	Maximum M&S Cost [\$]	PERT SWF Direct Costs [\$]	PERT M&S Direct Costs [\$]	TRAVEL [\$]	Overhead [\$]	Total M&S+SWF +OH [\$]	Budget Responsibility
1	Outer Vessel	Summary		255	508	866				416	118	124	4,840	14,090	24,220	0	0	0	0	62,930	
1.1.1	Outer Vessel	Disassembly	Disconnect O/V an	4	8	16	2.00	0.00	0.50	17	0	4	808	0	0	808	0	0	568	1,376 FERMI	FY11
1.1.2	Outer Vessel	Disassembly	Remove camera p	2	3	5	2.00	0.00	0.50	6	0	2	295	0	0	295	0	0	207	503 FERMI	FY11
1.1.3	Outer Vessel	Disassembly	Move water tank +	6	9	16	4.00	0.00	0.00	39	0	0	1,803	0	1,000	1,803	367	1,325	3,498 FERMI	FY11	
1.1.4	Outer Vessel	Disassembly	Remove O/V from i	1	3	5	3.00	0.00	0.00	9	0	0	420	0	0	420	0	0	295	714 FERMI	FY11
1.1.5	Outer Vessel	Disassembly	Move parts to DAE	2	3	5	3.00	0.00	0.00	10	0	0	443	0	0	443	0	0	311	754 FERMI	FY11
1.2.1	Outer Vessel	Repairs and Modifications to C	Rust Removal	2	6	10	1.00	0.00	0.00	6	0	0	280	0	1,000	280	500	277	1,057 FERMI	FY11	
1.2.2	Outer Vessel	Repairs and Modifications to C	Passivation Test	3	5	10	2.00	0.50	0.50	11	3	3	734	0	1,000	734	500	596	1,830 FERMI	FY11	
1.3.1	Outer Vessel	Move to SNOlab	Crate O/V/V asy.,	20	30	40	2.00	0.00	0.00	60	0	0	2,340	3,190	4,020	2,797	3,187	2,480	8,464 FERMI	FY11	
1.3.2	Outer Vessel	Move to SNOlab	Ship to SNOlab	6	16	20	1.00	0.00	0.00	15	0	0	1,800	2,100	2,400	699	2,100	831	3,630 FERMI	FY12	
1.3.3	Outer Vessel	Move to SNOlab	Move underground	8	16	32	2.00	0.00	0.00	35	0	0	0	0	0	0	0	0	0	0	SNO
1.3.4	Outer Vessel	Move to SNOlab	Uncrate	4	8	16	2.00	1.00	1.00	17	9	9	1,505	0	0	1,505	0	1,057	2,562 FERMI	FY12	
1.4.1	Outer Vessel	SNOlab assembly	Insert O/V into SNC	8	12	24	2.00	1.00	1.00	27	13	13	300	500	800	2,316	0	1,626	3,942 FERMI	FY12	
1.4.2	Outer Vessel	SNOlab assembly	New gaskets	1	1	3	2.00	0.00	0.00	3	0	0	124	0	0	124	517	171	812 FERMI	FY12	
1.4.3	Outer Vessel	SNOlab assembly	Connections to hv	8	24	80	2.00	1.00	1.00	61	31	31	200	1,000	2,000	5,326	1,033	3,907	10,267 FERMI	FY12	
1.4.4	Outer Vessel	SNOlab assembly	Assemble camera	8	24	80	2.00	1.00	1.00	61	31	31	200	1,000	2,000	5,326	1,033	3,907	10,267 FERMI	FY12	
1.4.5	Outer Vessel	SNOlab assembly	Leak Check	12	20	24	2.00	0.00	0.00	39	0	0	1,803	0	0	1,803	0	1,266	3,068 FERMI	FY12	
1.5	Outer Vessel	Canadian certification		160	320	480	0.00	0.10	0.10	0	32	32	2,574	0	10,000	5,000	5,000	2,616	10,190 FERMI	FY12	
2	Inner Vessel	Summary		255	520	1015				249	67	67	3,500	6,000	9,000	15,139	6,083	0	11,616	32,838	
2.0	Inner Vessel	Work plan for inner vessel		4	8	16	1.00	1.00	1.00	9	9	9	1,101	0	0	1,101	0	773	1,874 FERMI	FY11	
2.1	Inner Vessel	Extraction from Outer Vessel	Set IV on stand	4	8	16	2.00	0.00	0.00	17	0	0	808	0	0	808	0	568	1,376 FERMI	FY11	
2.2	Inner Vessel	Modifications	Replacement for J	20	40	80	1.00	0.25	0.50	43	11	22	2,892	1,000	2,000	2,892	1,083	2,206	6,181 FERMI	FY11	
2.3	Inner Vessel	Shipping	Ship inside OV	1	2	3	1.00	0.00	0.00	2	0	0	93	0	0	93	0	65	159 FERMI	FY12	
2.4	Inner Vessel	Receive IV at SNOlab		2	4	6	1.00	0.00	0.00	4	0	0	0	0	0	0	0	0	0	0	SNO
2.5	Inner Vessel	Move underground at SNOlab		8	16	32	2.00	0.00	0.00	35	0	0	0	0	0	0	0	0	0	0	SNO
2.6	Inner Vessel	Reassembly		8	12	16	2.00	0.00	0.00	24	0	0	1,119	0	0	1,119	0	786	1,905 FERMI	FY12	
2.7	Inner Vessel	Leak Check		4	6	8	2.00	0.00	0.00	12	0	0	569	0	0	569	0	393	952 FERMI	FY12	
2.8.0	Inner vessel	New vapor transfer line	Design	8	20	30	0.00	1.00	1.00	0	20	20	1,582	0	1,500	1,582	0	1,111	2,693 FERMI	FY12	
2.8.1	Inner vessel	New vapor transfer line	Procure parts	16	40	80	2.00	0.10	0.10	85	4	4	500	1,000	1,500	4,321	1,000	1,621	1,168 FERMI	FY12	
2.8.2	Inner vessel	New vapor transfer line	Build line	8	16	32	1.00	0.10	0.10	17	2	2	500	1,000	1,500	947	1,000	3,035	7,356 FERMI	FY12	
2.8.3	Inner vessel	New vapor transfer line	Line heater	4	8	16	0.00	0.00	0.00	0	0	9	0	0	0	0	0	0	827	2,775 FERMI	FY12
2.9.0	Inner vessel	Employing System	Conceptual design	4	8	16	0.00	0.00	0.00	0	0	9	0	0	0	0	0	0	0	0	FERMI
2.9.1	Inner vessel	Employing system	Design	8	20	40	0.00	1.00	1.00	0	21	2	0	0	0	1,716	0	1,205	2,921 FERMI	FY12	
2.9.2	Inner vessel	Employing system	Procure parts	80	160	320	0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	FERMI
2.10	Inner vessel	Cleaning					0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	FERMI
2.11	Inner vessel	Seals					0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	FERMI
2.13	Inner vessel	Spate parts					0.00	0.00	0.00	0	0	0	2,000	3,000	4,000	0	3,000	0	485	3,485 FERMI	FY12
3	High Purity Fluid Skid	Summary		230	457	745				180	58	104	4,487	12,453	21,819	13,099	12,686	0	11,251	37,036	
3.0	High Purity Fluid Skid	Work plan for high purity fluid skid		4	8	16	1.00	1.00	1.00	9	9	9	1,101	0	0	1,101	0	773	1,874 FERMI	FY11	
3.1	High Purity Fluid Skid	Remove from NuMI	Remove & ship to	2	3	5	2.00	0.00	0.00	6	0	0	295	0	0	295	0	207	503 FERMI	FY11	
3.2	High Purity Fluid Skid	Disassemble	Attempt to shrink t	2	6	10	2.00	0.00	0.00	12	0	0	559	0	0	559	0	393	952 FERMI	FY11	
3.3	High Purity Fluid Skid	Crate	T&M carpenter	6	8	10	0.00	0.00	0.00	0	0	0	887	1,053	1,219	0	1,053	170	1,223 FERMI	FY11	
3.4	High Purity Fluid Skid	Ship					0.00	0.00	0.00	0	0	0	1,100	1,400	1,600	0	1,383	224	1,607 FERMI	FY12	
3.5	High Purity Fluid Skid	Receive					0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
3.6	High Purity Fluid Skid	Transport underground					0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
3.7	High Purity Fluid Skid	Reassemble		20	40	60	2.00	0.00	0.00	80	0	0	3,730	0	0	3,730	0	2,619	6,349 FERMI	FY12	
3.8	High Purity Fluid Skid	Leak Check		8	16	40	2.00	0.00	0.00	37	0	0	1,740	0	0	1,740	0	1,222	2,963 FERMI	FY12	
3.10	High Purity Fluid Skid	Test		8	16	40	0.00	0.25	2.00	0	5	37	375	0	0	375	0	264	639 FERMI	FY12	
3.11	High Purity Fluid Skid	Operations procedures update		4	8	16	0.00	0.25	1.00	0	2	9	174	0	0	174	0	122	297 FERMI	FY12	
3.12	High Purity Fluid Skid	Readiness review		4	8	16	0.00	0.25	1.00	0	2	9	174	0	0	174	0	122	297 FERMI	FY12	
3.13	High Purity Fluid Skid	Spare parts					0.00	0.00	0.00	0	0	0	0	0	2,000	0	1,000	162	1,163 FERMI	FY12	
3.14	High Purity Fluid Skid	Consumables					0.00	0.00	0.00	0	0	0	1,000	2,000	4,000	0	2,167	350	2,517 FERMI	FY12	
3.15	High Purity Fluid Skid	Canadian certification		160	320	480	0.00	0.10	0.10	0	32	32	2,574	0	5,000	10,000	5,000	2,616	10,190 FERMI	FY12	
3.16	High Purity Fluid Skid	Connections to lab water and gas		4	8	20	2.00	0.00	0.00	19	0	0	500	1,000	2,000	870	1,083	786	2,740 FERMI	FY12	
3.17	High Purity Fluid Skid	Modifications to support emptying operation		8	16	32	1.00	0.50	0.50	17	9	9	1,000	1,000	1,000	1,505	1,000	1,219	3,724 FERMI	FY12	
4	Water Tank	Summary		136	244	416				203	98	9	5,064	62,271	19,128	17,335	3,586	0	12,756	33,686	
4.0	Water Tank	Work plan for water tank					0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
4.1	Water Tank	Specify	Tank				0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
4.1.0	Water Tank	Specify	Insulation				0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
4.1.1	Water Tank	Specify	Lid				0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
4.1.2	Water Tank	Specify	Feedthroughs				0.00	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	SNO
4.1.3	Water Tank	Specify	Water supply				0.00	0.00	0.00												





7.0	Utilities	Specify requirements	4	8	16	1.00	1.00	1.00	9	9	1,101	0	773	1,874	FY11
7.1.0	Utilities	Electrical Design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.1.1	Utilities	Electrical Design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.1.2	Utilities	Electrical Design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.1.3	Utilities	Electrical Design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.1.4	Utilities	Electrical Design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.1.5	Utilities	Electrical Design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.2	Utilities	Water distribution design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.3.0	Utilities	Compressed air design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.3.1	Utilities	Compressed air design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.4.0	Utilities	Communications design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.4.1	Utilities	Communications design			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.5	Utilities	Design review			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.0	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.1	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.2	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.3	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.4	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.5	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.6.6	Utilities	Procure electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.7.1	Utilities	Procure water equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.7.2	Utilities	Procure water equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.7.3	Utilities	Procure water equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.8.1	Utilities	Procure compressed air equip			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.8.2	Utilities	Procure compressed air equip			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.9	Utilities	Procure network equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.10	Utilities	Install electrical equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.11	Utilities	Install water equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.12	Utilities	Install compressed air equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.13	Utilities	Install communications equipment			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
7.14	Utilities	Readiness review			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 SNO
8	Cameras	Summary	992	1802	3640			47,000	104	43	798	0	11,445	54,400	
8.1	Cameras	Plan for camera upgrades	30	40	120	0.00	0.00	0.00	0	0	52	0	0	0	0 UoC
8.2	Cameras	Research new camera system	120	160	320	0.00	0.00	0.00	0	0	180	0	0	0	0 UoC
8.3	Cameras	Get camera loan for test	80	160	240	0.00	0.00	0.00	0	0	16	0	0	0	0 UoC
8.4	Cameras	Test new camera	100	200	400	0.00	0.00	0.00	0	0	217	0	0	0	0 UoC
8.5	Cameras	New camera decision	30	40	120	0.00	0.00	0.00	0	0	52	0	0	0	0 UoC
8.6.0	Cameras	First batch	80	160	320	0.00	0.00	0.00	0	0	17	0	0	0	0 UoC
8.6.1	Cameras	First batch	80	160	320	0.00	0.00	0.00	0	0	17	0	0	0	0 UoC
8.6.2	Cameras	First batch	80	160	320	0.00	0.00	0.00	0	0	17	0	0	0	0 UoC
8.6.3	Cameras	Second batch	80	160	320	0.00	0.00	0.00	0	0	17	0	0	0	0 UoC
8.6.4	Cameras	Second batch	80	160	320	0.00	0.00	0.00	0	0	17	0	0	0	0 UoC
8.6.5	Cameras	Second batch	80	160	320	0.00	0.00	0.00	0	0	17	0	0	0	0 UoC
8.7.0	Cameras	Camera mounts and enclosure Design	20	40	80	0.00	0.00	0.00	0	0	43	0	0	0	0 UoC
8.7.1	Cameras	Camera mounts and enclosure Build	15	30	60	0.00	0.00	0.00	0	0	8	0	0	0	0 UoC
8.7.2	Cameras	Camera mounts and enclosure Test	15	30	60	0.00	0.00	0.00	0	0	8	0	0	0	0 UoC
8.9	Cameras	Camera Trigger Software	30	40	100	0.00	0.00	0.00	0	0	48	0	0	0	0 UoC
8.10	Cameras	Test new cameras with new DAQ software	20	30	60	0.00	0.00	0.00	0	0	33	0	0	0	0 UoC
8.11	Cameras	Readiness review	5	10	20	0.00	0.00	0.00	0	0	11	0	0	0	0 UoC
8.12	Cameras	Mount final camera system on OV	5	10	20	0.00	0.00	0.00	0	0	3	0	0	0	0 UoC
8.13	Cameras	Align and calibrate cameras	30	40	80	0.25	0.00	0.00	11	0	45	0	0	0	0 UoC
8.14	Cameras	Camera cabling	6	6	20	1.00	0.00	0.00	8	0	8	0	0	0	0 UoC
8.15	Cameras	Camera enclosure leak check	6	6	20	1.00	0.00	0.00	8	0	2	0	0	0	0 UoC
9	Data Acquisition	Summary	103	188	563			33,000	16	0	214	0	3,840	25,118	
9.0	Data Acquisition	Work plan for DAQ	10	16	40	0.00	0.00	0.00	0	0	19	0	0	0	0 UoC
9.1	Data Acquisition	PXI Cables	10	16	40	0.00	0.00	0.00	0	0	19	0	0	0	0 UoC
9.1	Data Acquisition	Software	10	16	40	0.00	0.00	0.00	0	0	19	0	0	0	0 UoC
9.2	Data Acquisition	Digitizers	8	40	200	0.00	0.00	0.00	0	0	61	0	0	0	0 UoC
9.3	Data Acquisition	Racks	2	4	8	0.00	0.00	0.00	0	0	2	0	0	0	0 UoC
9.4	Data Acquisition	Modify DAQ software to work with new modules (i	30	40	120	0.00	0.00	0.00	0	0	52	0	0	0	0 UoC
9.5	Data Acquisition	Ship DAQ to Srolab	4	6	15	1.00	0.00	0.00	7	0	0	0	0	0	0 UoC
9.6	Data Acquisition	Install at SNOlab	12	16	40	0.00	0.00	0.00	0	0	19	0	0	0	0 UoC
9.7	Data Acquisition	Test DAQ	12	24	40	0.00	0.00	0.00	0	0	25	0	0	0	0 UoC
9.8	Data Acquisition	Readiness review	5	10	20	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10	Computing	Summary	188	372	640			21,500	0	0	178	0	3,603	21,222	
10.0	Computing	Work plan for Computing	4	8	16	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10.1.1	Computing	Computers			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10.1.2	Computing	Computers			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10.1.3	Computing	Computers			0.00	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10.2	Computing	Storage	8	12	40	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10.3	Computing	System administration	8	16	32	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC
10.4	Computing	Licenses	20	40	60	0.00	0.00	0.00	0	0	0	0	0	0	0 UoC





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## U.S. Department of Energy

## Budget Page

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OMB Control No.

1910-1400

OMB Burden Disclosure

Statement on Reverse

## Year 1 Funding Proposal

03/1/2011 through 9/30/2011

ORGANIZATION <b>FERMILAB</b>						Budget Page No: <u>1</u>	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR <b>Andrew Sonnenschein</b>						Requested Duration: <u>12</u> (Months)	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)						DOE Funded Person-mos.	
						CAL	ACAD
						SUMR	
						Funds Requested by Applicant	Funds Granted by DOE
PPD							
2.							
3.							
4.							
5.							
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)							
7. ( ) TOTAL SENIOR PERSONNEL (1-6)							
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)							
1. ( ) POST DOCTORAL ASSOCIATES							
2. ( 1.48 ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) .35 Eng., 1.13 Tech Spec						17.80	\$127,608
3. ( ) GRADUATE STUDENTS							
4. ( ) UNDERGRADUATE STUDENTS							
5. ( ) SECRETARIAL - CLERICAL							
6. ( ) OTHER							
TOTAL SALARIES AND WAGES (A+B)							\$127,608
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)							\$40,835
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)							\$168,443
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)							
TOTAL PERMANENT EQUIPMENT							
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)							\$32,500
2. FOREIGN							
TOTAL TRAVEL							\$32,500
F. TRAINEE/PARTICIPANT COSTS							
1. STIPENDS (Itemize levels, types + totals on budget justification page)							
2. TUITION & FEES							
3. TRAINEE TRAVEL							
4. OTHER (fully explain on justification page)							
TOTAL PARTICIPANTS ( ) TOTAL COST							
G. OTHER DIRECT COSTS							
1. MATERIALS AND SUPPLIES							\$151,619
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION							
3. CONSULTANT SERVICES							
4. COMPUTER (ADPE) SERVICES							
5. SUBCONTRACTS							
6. OTHER							
TOTAL OTHER DIRECT COSTS							\$151,619
H. TOTAL DIRECT COSTS (A THROUGH G)							\$352,562
I. INDIRECT COSTS (SPECIFY RATE AND BASE) 11.7% on Travel expense, 1.5% on Subcontracts, 16.17% on all other M&S expense, 70.23% on SWF							
TOTAL INDIRECT COSTS							\$146,617
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)							\$499,178
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES							
L. TOTAL COST OF PROJECT (J+K)							\$499,178

**U.S. Department of Energy**  
**Budget Page**  
(See reverse for Instructions)

VIPRAM

Year 2 Funding Proposal

10/1/2011 through 9/30/2012

ORGANIZATION FERMILAB				Budget Page No: <u>2</u>	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Andrew Sonnenschein				Requested Duration: <u>12</u> (Months)	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)				DOE Funded Person-mos.	
				CAL	ACAD
				SUMR	
				Funds Requested	
				by Applicant	
				Funds Granted	
				by DOE	
1.	0	PPD	-	0.00	0.00
2.					
3.					
4.					
5.					
6.	( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)				
7.	( 0.00 )	TOTAL SENIOR PERSONNEL (1-6)	0.00		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1.	( )	POST DOCTORAL ASSOCIATES			
2.	( 1.49 )	OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) .451 Eng., 1.036 Tech Spec	17.88		
3.	( )	0			
4.	( )	UNDERGRADUATE STUDENTS			
5.	( )	SECRETARIAL - CLERICAL			
6.	( )	OTHER			
TOTAL SALARIES AND WAGES (A+B)					
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)					
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)					
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)					
TOTAL PERMANENT EQUIPMENT					
E. TRAVEL				1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)	
				2. FOREIGN	
TOTAL TRAVEL					
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (Itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( 0 )				TOTAL COST	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES					
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					
3. CONSULTANT SERVICES					
4. COMPUTER (ADPE) SERVICES					
5. SUBCONTRACTS					
6. OTHER					
TOTAL OTHER DIRECT COSTS					
H. TOTAL DIRECT COSTS (A THROUGH G)					
I. INDIRECT COSTS (SPECIFY RATE AND BASE) 11.7% on Travel expense, 1.5% on Subcontracts, 16.17% on all other M&S expense, 70.23% on SWF					
TOTAL INDIRECT COSTS					
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)					
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J+K)					

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**Budget Page**

(See reverse for Instructions)

OMB Control No.  
1910-1400

OMB Burden Disclosure  
Statement on Reverse

**TOTAL of 2 Year Funding Proposal**

**3/1/2011 through 9/30/2012**

ORGANIZATION <b>FERMILAB</b>				Budget Page No: <u>6</u>		
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR <b>Andrew Sonnenschein</b>				Requested Duration: <u>24</u> (Months)		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)			DOE Funded Person-mos.		Funds Requested by Applicant	Funds Granted by DOE
			CAL	ACAD	SUMR	
1. <u>0</u>			0.00	0.00	0.00	\$0
2.						
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)						
7. ( <u>0.00</u> ) TOTAL SENIOR PERSONNEL (1-6)			0.00			\$0
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. ( <u>0.00</u> ) POST DOCTORAL ASSOCIATES			0.00			\$0
2. ( <u>2.97</u> ) OTHER PROFESSIONAL (TECHNICIAN, PROGRAMMER, ETC.) Elec. Eng			35.68			\$261,533
3. ( <u>0.00</u> ) GRADUATE STUDENTS			0.00			\$0
4. ( <u>0.00</u> ) UNDERGRADUATE STUDENTS			0.00			\$0
5. ( <u>0.00</u> ) SECRETARIAL - CLERICAL			0.00			\$0
6. ( <u>0.00</u> ) OTHER			0.00			\$0
TOTAL SALARIES AND WAGES (A+B)						\$261,533
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS) VACATION+OPTO+FRINGE						\$83,691
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)						\$345,224
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM.)						
TOTAL PERMANENT EQUIPMENT						
E. TRAVEL			1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)		\$208,764	
			2. FOREIGN		\$0	
TOTAL TRAVEL					\$208,764	
F. TRAINEE/PARTICIPANT COSTS						
1. STIPENDS (Itemize levels, types + totals on budget justification page)					\$0	
2. TUITION & FEES					\$0	
3. TRAINEE TRAVEL					\$0	
4. OTHER (fully explain on justification page)					\$0	
TOTAL PARTICIPANTS ( ) TOTAL COST					\$0	
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES					\$496,193	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION					\$0	
3. CONSULTANT SERVICES					\$0	
4. COMPUTER (ADPE) SERVICES					\$0	
5. SUBCONTRACTS					\$0	
6. OTHER					\$0	
TOTAL OTHER DIRECT COSTS					\$496,193	
H. TOTAL DIRECT COSTS (A THROUGH G)					\$1,050,181	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) 11.7% on Travel expense, 1.5% on Subcontracts, 16.17% on all other M&S expense, 70.23% on SWF TOTAL INDIRECT COSTS					\$347,110	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)					\$1,397,291	
K. AMOUNT OF ANY REQUIRED COST SHARING FROM NON-FEDERAL SOURCES						
L. TOTAL COST OF PROJECT (J+K)					\$1,397,291	